NASA Technical Memorandum 104810

Space Shuttle Orbiter Corrosion History, 1981-1993

A Review and Analysis of Issues Involving Structures and Subsystems

A report of the
Orbiter Corrosion Control Review Board

June 1995

This publication is available from the NASA Center for AeroSpace Information,
800 Elkridge Landing Road, Linthicum Heights, MD 21090-2934 (301) 621-0390.

Outgoing Chairman's Message

In 1992, I proposed a long term corrosion inspection plan for orbiter skin under tile. During a discussion of the proposal, the orbiter management team asked a number of interesting questions. How do we determine where hidden corrosion may exist? How do we know corrosion doesn't exist in areas that aren't inspected? How are the various orbiter corrosion prevention systems holding up? What new corrosion prevention systems should be implemented? When is corrosion a repair problem and when is it simply a nuisance? How can corrosion maintenance costs be reduced with no impact to orbiter safety? This is only a partial list. Some of these questions had been previously addressed for individual subsystems; however, an integrated vehicle assessment had never been performed.

The Corrosion Control Review Board was proposed a few months later as a mechanism for answering questions such as those indicated above. Our first effort involved producing a list of all active orbiter corrosion. This list is now maintained continuously and serves as a single point of reference with respect to corrosion for orbiter management. Our second major effort was the generation of this report, which describes orbiter corrosion issues from historical perspective. Future reports will contain specific recommendations for long term orbiter corrosion activities.

I believe the Corrosion Control Review Board has been a success. Using existing level-of-effort labor resources and no supplemental funding, we have significantly enhanced capabilities for reporting, tracking, and resolving orbiter corrosion issues. I have enjoyed serving as chairman of the Corrosion Control Review Board and I have developed a high level of confidence in the capabilities and dedication of the civil service and contractor personnel who serve as boardmembers. I am confident that this board will experience even greater appreciation in the years to come.

Charles Salkowski
Chairman, Orbiter Corrosion Control Review Board, 1993-1994

Incoming Chairman's Message

On behalf of past and current Corrosion Control Review Board (CCRB) members, I would like to express the board's sincere appreciation to the outgoing chairman, Mr. Charles Salkowski. The CCRB was formed as a direct result of his efforts, and the leadership he provided during his tenure has been instrumental to the development of the CCRB's role as a valuable technical and programmatic resource in support of the Orbiter Project.

Several areas of activity initiated by Mr. Salkowski, such as the CCRB Corrosion Database project, have been enthusiastically received, and will continue to be supported to meet the evolving needs of the aging orbiter fleet. Support for these activities and for the board's charter responsibilities for structural and subsystem corrosion will provide the basic framework for the CCRB in 1995, and this core effort will ensure operational continuity of the board.

In addition, during 1995 the CCRB will begin to explore more proactive approaches to long-term corrosion protection. The board, in conjunction with its contacts in the military and civilian aerospace communities, will expand its efforts to identify new and/or advanced corrosion protection technologies which have potential applicability to the orbiter fleet. The CCRB will advocate and initiate testing and evaluation of these technologies with a maximum utilization of level-of-effort resources, and establish a collective expertise in new and state-of-art methods of corrosion protection.

The comprehensive knowledge of corrosion protection technology will be applied to the development of improved corrosion prevention strategies for regions of recurrent orbiter corrosion identified in the current report. Following the lead of previous CCRB activities, such strategies will be formulated with full considerations for programmatic consistency, ease of operational implementation, and cost effectivity, as well as for technical value. These recommendations will provide the basis for future reports in this series.

Glen S. Nakayama
Chairman, Orbiter Corrosion Control Review Board

Orbiter Corrosion Control Review Board Membership as of January 1, 1995

Yannet F. Brister (Analyst)	Rockwell Aerospace
Jeffrey D. Caratelli	Lockheed Space Operations Company
Thomas E. Collins	Rockwell Aerospace
Frank V. Daniels	Rockwell Aerospace
Marie A. Havican	NASA Lyndon B. Johnson Space Center
Harold S. Issen	Lockheed Space Operations Company
Glen S. Nakayama, Ph.D. (Chair)	NASA Lyndon B. Johnson Space Center
Christopher B. Rawlins	Rockwell Aerospace
Peter Richiuso	NASA John F. Kennedy Space Center
Richard W. Russell	NASA John F. Kennedy Space Center

Other Individuals Who Contributed to This Report:

Charles L. Salkowski, (CCRB Chairman 1993-94)	NASA Lyndon B. Johnson Space Center
Chien V. Ngyuen	NASA John F. Kennedy Space Center
Peter N. Sanstead	Lockheed Space Operations Company
Marcella Solomon	Rockwell Aerospace

Contents

Tables

Figures

Acronyms and Abbreviations

A&P	airframe and power plant
APU	auxiliary power unit
ATP	acceptance test procedure
CAR	corrective action request
CCRB	Corrosion Control Review Board
CPC	corrosion preventive compounds
CRES	corrosion resistant steel
DHS	dome heat shield
DR	discrepancy report
ECO	engineering change order
EICN	end item control number
ET	external tank
FAA	Federal Aviation Administration
	false alarm avoidance
FCPV	
FRCS	forward reaction control system (subsystem)
GGVM	gas generator valve module
KSC	Kennedy Space Center
LCC	Launch Control Center
LH	left-hand
LRU	line replaceable unit
LSOC	Lockheed Space Operations Company
MCR	material change request
MDD	mate/demate device
MLP	Mobile Launch Platform
MMH	maintenance man-hour
	monomethylhydrazine
M&P	materials and processes
MPS	main propulsion system(subsystem)
MR	material review
MRB	material review board
MUA	material usage agreement
N_2O_4	nitrogen tetroxide
N_2H_4	hydrazine
NASA	National Aeronautics and Space Administration
NDE	nondestructive evaluation
NH_3	ammonia

NSLD	NASA Shuttle Logistics Depot
OMDP	orbiter maintenance down period
OMRSD	Operations Maintenance Requirements Specifications Document
OMS	orbiter maneuvering system(subsystem)
OJT	on-the-job training
OPF	Orbiter Processing Facility
PC	personal computer
PR	problem report
PRACA	problem reporting and corrective action
PRSD	power reactant storage and distribution
	power reactant supply and distribution system
QA	quality assurance
QC	quality control
QE	quality engineering
RCC	reinforced carbon to carbon
RCN	requirements change notice
RH	right-hand
RI-LSS	Rockwell International Corporation-Launch Support Service
RSB	rudder speed brake
RTB	resistance temperature bulb
RTV	room temperature vulcanized (silicone compound)
SCA	Shuttle Carrier Aircraft
SCC	stress corrosion cracking
SMSG	Shuttle Maintenance Steering Group
SSME	space shuttle main engine
STS	Space Transportation System
TCS	thermal control system(subsystem)
TPS	thermal protection system
TRSD	Test Requirements Specification Document
VAB	Vehicle Assembly Building
WAD	Work Authorizing Document
WLE	wing leading edge

1.0 Introduction

1.1 Overview and Intent

The first space shuttle orbiter flight was launched on April 12, 1981. The original design life was 10 years or 100 missions. Since then, each orbiter except Endeavour (OV-105) has flown at least 12 missions; OV-102 (Columbia) has flown over 18 missions (table 1). Currently, plans are under consideration to continue flying the space shuttle until as late as the year 2020. Although the orbiter was designed for extended use, a review of corrosion mitigation methods is essential for an additional 25 years of operation.

Table 1. Orbiter Vehicle Age Life (as of 1/94)

Vehicle	Missions	Years in Service
OV-99	10	3
OV-102	15	13
OV-103	18	10
OV-104	12	9
OV-105	5	2

Although the orbiter flight and ground environment is often compared to that of commercial and military aircraft, there are significant differences. This is made evident by the relatively small number of orbiter corrosion problems experienced to date. However, trends indicate a gradual increase in corrosion reports in recent years, which is not unexpected as the orbiters age.

The intent of this volume of the corrosion report is to review all measures taken to limit orbiter corrosion, from design considerations through operational maintenance. The corrosion that has occurred is analyzed to identify possible inconsistencies in rationale, unavoidable environmental conditions, and/or design shortfalls.

1.2 Orbiter Corrosion Control Review Board Charter

In a world of aging aerospace vehicles, there is ample precedent for a dedicated corrosion control review team. Each manufacturer of civilian and military aircraft in America has assembled a general company corrosion panel or, in many cases, aircraft-unique panels designed to follow corrosion issues. Some defense agencies, such as the U.S. Navy, require that a dedicated manufacturer-led corrosion prevention panel be formed for all new aircraft designs. This team is active from the design phase through the operational life of the aircraft.

During the 1980s, Boeing Commercial Airplanes initiated a series of aging fleet evaluations. It was determined that some operators do not utilize a proven corrosion prevention and control program, which led, in certain cases, to unacceptable degradation of structural integrity and, in extreme instances, to the loss of an airplane. Boeing established a corrosion prevention and control team to identify all known corrosion problems that could affect continuing airworthiness of the aging fleet and to summarize existing maintenance recommendations. Although this effort was initially performed to address the aging fleet, Boeing stresses that such programs should be initiated early, because the corrosion threshold of some structures is as short as 5 to 6 years.

In July 1993, the Orbiter Project Corrosion Control Review Board (CCRB) was established and chartered to advise the Project and initiate resolutions for technical and operational activities involving corrosion. Specific responsibilities include corrosion assessment, corrective actions, and corrosion control and prevention.

The CCRB reviews active corrosion issues and ensures that the appropriate personnel are involved in their resolution. Appropriate personnel, at minimum, include representatives from system, materials, and quality engineering areas. A list of active corrosion issues is updated continuously through inputs from project management, system managers, and a corrosion database which is derived from the Orbiter Problem Reporting and Corrective Action (PRACA) System. In keeping with the proactive and preventive nature of the CCRB, additional corrosion issues are also considered. Telecons are conducted to review, status, and obtain consensus on active corrosion issues. Summaries are prepared as required for the orbiter project and subsystem management.

By December 1993, 28 corrosion issues were identified as significant enough to require CCRB review. Fifteen issues were resolved, with CCRB recommendations implemented and/or forwarded to the appropriate management office. The most notable issue in 1993 was external rudder speed brake (RSB) corrosion. A resolution involving stripping and repainting the RSB and performing regular washes at Kennedy Space Center (KSC) was developed by the CCRB and approved by the subsystem manager and the Manager, Orbiter and GFE Projects office.

1.3 KSC Corrosion Database

A corrosion database was created by the KSC CCRB representatives via a historical review of the KSC PRACA database, which was established in 1983. The PRACA database tracks all nonconformances reported on shuttle hardware detected at KSC, at Palmdale during orbiter maintenance down period (OMDP), or in flight. The nonconformances (problem reports (PRs) and material reviews (MRs)) are input into the PRACA database when detected; each entry includes all information found in the 39 numbered data points on the first page of the referenced work authorizing document (WAD). Entries are updated daily with resulting disposition and summary as required, until the WAD is closed.

The PRACA database was searched for the problem description and disposition summary for all entries written against orbiter vehicle corrosion. This search used the key words *corrosion, crack(s), scratch(es), discoloration, stain(s), rust, oxidation, pit(s), pitting, foreign, erosion* and *scored*. The following data points were selected from the 39 possible as output: PR number, status, when detected, work area, orbiter location, orbiter zone, report date, end item control number (EICN) 1 & 2, part name, part number, serial number, replacement serial number, STS effectivity, datacode, description, and disposition. After reviewing the data from this initial query, the key word list was reduced to *corrosion, rust, oxidation and pits/pitting*, resulting in a more efficient and usable output.

The PRACA entries concerning corrosion targeted by this historical query were entered into a database by RI-LSS personnel utilizing Macintosh Filemaker software. The Filemaker database is more user friendly and flexible than the KSC PRACA system; it can be accessed through networks by both Macintosh and PC workstations. Information provided through the KSC PRACA system is presently being provided for entry into the Filemaker database on a monthly basis and includes those WADs that have been closed since initial entry and open WADs written within the previous month. In this manner all WADs initially entered as open will be updated and the summary rationale added to complete the entry. Monthly updates reflect certain milestones in orbiter processing; i.e., the quantity of new WADs increases at roll-in to the Orbiter Processing Facility (OPF), while WADs closure increases at roll-out from the OPF and before launch.

Currently, efforts are under way by RI-LSS personnel to include corrosion information not located in the KSC PRACA database. Data sources include the corrective action request (CAR) database maintained by Rockwell at Downey and a database under development at the NASA Shuttle Logistics Depot (NSLD). The CAR database includes all Shuttle Project CARs generated over the life of the program. The NSLD database will include those WADs initiated at the NSLD. Queries of these databases will provide data on corrosion that may be invisible to the KSC PRACA system, i.e., data obtained upon tear down and failure analysis of a part or subsystem. The addition of these sources to the database will provide a more complete historical overview of a corrosion issue. The goal of the database is to aid in real-time corrosion problem solving and tracking, as well as to provide trend analysis through historical data.

2.0 Design Considerations

2.1 Predicted Corrosion Environment

The Space Shuttle experiences corrosion environments from benign to severe as it progresses from flight to flight. The relative severity, as evaluated by the CCRB, of each environment is illustrated in figure 1. The orbiters are stored in the OPF, in which buildings are temperature- and humidity-controlled. When moved to the launch pad, each orbiter is subjected to an almost constant salt spray from the nearby Atlantic Ocean. In addition, the high humidity allows the formation of condensation on all surfaces open to the atmosphere. Once the orbiter reaches low earth orbit, any water that may have collected during earlier exposure evaporates in the vacuum of space. On landing, the orbiter must be deserviced; during this period it is exposed to whatever the environment is at the landing site. If the orbiter lands in California, it must be ferried across the country to KSC. This is additional exposure to an uncontrolled environment until the orbiter returns to the OPF. All these factors were taken into account when the overall corrosion protection scheme was developed.

2.2 General Guidelines

Rockwell's proposal for corrosion protection of the orbiter was based on no structural failure due to corrosion within a 10-year or 100-mission life. A detailed material control plan addressing every material that would be utilized on the orbiter was implemented. The plan required that all metals meet what was termed an ‘A’ rating for corrosion and/or stress corrosion. Metallic materials were evaluated either by test or engineering judgment to meet these NASA Level II requirements.

Metals were required to meet MSFC-SPEC-250, class II requirements. Metals not listed in the specification were subjected to a 1500-hour salt spray test. Metallic materials that were proposed for use but not ‘A’ rated by MSFC-SPEC-250 (accepted for unrestricted use with respect to corrosion) were evaluated by their use, location, or protection schemes and upgraded to ‘A’ status if possible.

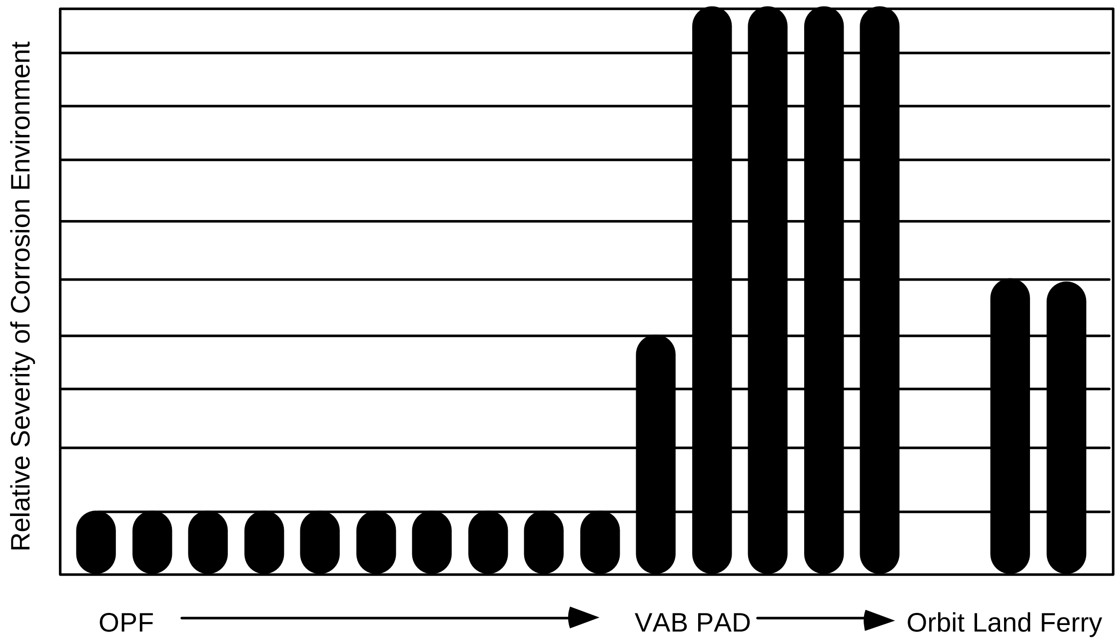

Figure 1. Variation of corrosion environment during typical flow.

Rockwell used MSFC-SPEC-522 as a guideline for determining the rating of material for stress corrosion cracking (SCC). For instance, the requirement for aluminum alloys is freedom from cracking after 30 days alternate exposure in a 3.5% sodium chloride solution while stressed to 75% of the material's yield strength. However, where essential materials were used that did not meet the 'A' rating, the designer would consider, as a minimum, the following actions to reduce the probability of stress corrosion:

a) Selecting less susceptible alloys or tempers.
b) Reducing sustained stress levels on the part below stress corrosion threshold levels.
c) Protecting the part from the detrimental environment by hermetically sealing or coating the part or by inhibiting the environment.
d) Avoiding or reducing residual stresses in parts or assemblies by stress relieving, by avoiding interference fits, or by shimming assemblies.
e) Avoiding galvanic couples which may tend to accelerate the stress corrosion.
f) Providing for regular inspection of parts to determine surface flaws and cracking during the life cycle of the part.
g) Improving the surface quality of the part by reducing surface roughness or increasing surface compressive stresses.

Approval of any of these actions again had to be approved by Rockwell M&P and NASA through a material usage agreement (MUA).

Additionally, the Rockwell Standard Design Manual restricts the use of galvanically dissimilar metals by requiring that they not be used in contact unless suitably protected against electrolytic corrosion. Faying surfaces of dissimilar metals must be sealed against water intrusion or separated with a layer of corrosion-inhibiting epoxy or room-temperature vulcanized (RTV) silicone rubber. Dissimilar metals were considered compatible if they were in the same grouping as specified in MSFC-SPEC-250, or if the difference in potential was $\leq$ 0.25 volts. Also imposed was the requirement that all fasteners be installed wet with epoxy. The epoxy of choice was a chromated primer known under the brand name Super Koropon.

To address specific corrosion problems associated with aluminum alloys, additional restrictions were applied. Alloys susceptible to exfoliation were eliminated from design consideration as were all forms of alloys that exhibit stress corrosion thresholds of less than 25 KSI.

2.3 Special Considerations

A dry nitrogen gas system was implemented to purge the interior spaces of the orbiter vehicle. The purpose of the purge is to maintain a dry environment by preventing condensation. The nitrogen purge is continuously operating while the vehicle is in the Vehicle Assembly Building (VAB) and again, once the vehicle has been mounted on the Mobile Launch Platform (MLP). To date, there have been no significant corrosion issues in any areas of the vehicle maintained with this purge.

2.4 Water Intrusion/Entrapment Design Features

Drain holes were designed into the orbiter to prevent water from accumulating within the open orbiter structure. The drains were placed in selected areas of the structure so that drainage will occur in both horizontal and vertical orientations.

3.0 Inspection And Reporting

3.1 Inspection Requirements

Most of the orbiter recurring inspection requirements originate from the Operations Maintenance Requirements and Specification Document (OMRSD) V30 (Air Frame Inspection) and V31 (Zonal Inspection) documents. As indicated by Note R-2 adjacent to V30GEN.010 para. 3.2.2, "The inspection requirements in this document are designed to detect damage/deterioration resulting from service and age." The inspector is to verify that there are no cracks or corrosion in the structure or in fillet radii and notched areas.

There are four levels of inspections. Level A, External Surveillance, is used for detecting obvious discrepancies in externally visible structure, systems, and components. Level B. Internal Surveillance, is used for detecting similar conditions in internal structure. Level B may include the use of a borescope.

Level C, Detailed, is an intensive visual check of a specified area. Inspection aids such as mirrors or a hand lens may be required, and a borescope is recommended when access is confined. This inspection level, however, has been the source of some misunderstanding in the past. This is because the V30-10001 Job Card defines the distance to be used for this inspection level normally to be not greater than 18 inches. Areas found to be suspect at this distance should then be examined more closely to confirm findings. It is noted that minor corrosion may therefore not be detected using Level C. This is not an indication that the inspection was performed improperly, but that the corrosion was too minor to be seen at 18 inches.

Level D, Special Detailed, is an intensive check of a specified location which includes a special technique, such as nondestructive evaluation (NDE) or high-magnification borescope, and for which some disassembly may be required.

The requirements for inspection frequency vary in accordance with OMRSD requirements. For example, some inspections are performed every flight, some have a five-flight interval between inspections, and some are performed only at orbiter maintenance down period (OMDP). Detection of corrosion in a particular area has resulted in initiation of a requirements change notice (RCN) to change the inspection level or frequency. Or the area may be called out as a specific point of interest to be examined in future inspections. Thus, once corrosion is found in an area, that area is commonly inspected with the awareness that it has had a history of corrosion.

Additional inspections are required as a result of PRs and special requests from KSC and JSC engineering organizations. Subsystems have individual inspection requirements in the OMRSD as well.

3.2 Inspection Methods

ost inspections for corrosion on the orbiter are visual. Inspection Levels A, B, and C (noted previously) are visual checks, which may include use of a borescope, flashlight, hand lens (typically 5X or 10X), and mirror. Removal of fairings, access doors, thermal control system (TCS), liners, etc. may be required, as well as surface cleaning.

Inspection Level D, Special Detailed, uses a high-magnification borescope or NDE methods including penetrant testing, eddy current, ultrasonic, or X-radiography. These methods have been augmented with photography and videotape recording. Corrosion pit depth measurements have been made with dental molds.

Visual inspections performed apart from normal processing and the OMRSD-required checks have also detected corrosion. Teardown and refurbishment activities at the manufacturer and at NSLD have detected corrosion in hardware that was not evident via other means.

Other methods for detecting corrosion include various modes of hardware performance degradation. Examples include pressure loss in the ammonia boiler heat exchanger, flow rate reduction in the Freon cooling loop, and fuel cell leakage causing manifold pressure decay.

3.3 Corrective Action Reporting (CAR) Process

When corrosion and other anomalies deviating from design specifications are detected, they are reported using PRACA. Information from this computerized system is available at Rockwell-Downey, JSC, and KSC, and includes problem description, part number, probable cause, and disposition. The purpose of the problem reporting system is to ensure adequate visibility of nonconformances that require engineering input for resolution.

A proposed repair for a problem that cannot be resolved by returning the discrepant hardware to design specification requires approval of the Material Review Board (MRB). The MRB is an element project-level engineering and quality board chaired to review nonconforming material.

Recurring problems detected in flight hardware are addressed through corrective action and recurrence control. Action is taken to correct, reduce the incidence of, and prevent the recurrence of nonconformances.

4.0 Structural Corrosion History

Throughout orbiter history, numerous discrepancy reports have been written to document corrosion on many different flight hardware assemblies. Most of these discrepancies indicate minor structural surface corrosion. In these cases, the corrosion is removed mechanically or chemically, and the surface coating is reapplied. This repair is performed only when the structural integrity of the assembly can be maintained. When the corrosion has been severe enough to affect the margin of safety, doublers have been added, e.g., wing leading edge (WLE) spar and rudder speed brake (RSB) panels. In some instances, corrosion of fasteners has been severe enough to warrant removal and replacement. In areas where galvanic (dissimilar metal) corrosion has occurred and the Koropon protective coating was insufficient, a barrier layer of RTV may have been added to prevent recurrence. It is important to note that all structural corrosion instances are evaluated on a case-by-case basis (see section 5.1).

4.1. Fleet-Wide Corrosion Issues

Following is a list of selected issues from the KSC PRACA database as tracked by the CCRB:

a. Wing Leading Edge Spars. The WLE spar is constructed of either an aluminum honeycomb sandwich panel (OV-102) or a corrugated aluminum alloy approximately 0.040 inches thick (OV-103 and subs). The leading edge surfaces are lined with Inconel thermal control system (TCS) blankets. Attached spar fittings hold the reinforced carbon to carbon (RCC) panels which give the wing its characteristic airfoil shape and thermal protection. Three of the 22 RCC panels and the associated Inconel TCS blankets and spar fittings are removed at each orbiter processing flow to perform a sampling type inspection of the WLE for corrosion, with a contingency that the entire wing spar be inspected between OMDP periods. The forward surfaces of the corrugations are coated with room temperature vulcanization (RTV) to inhibit the formation of dissimilar metal corrosion. However, the set-back surfaces have only the basic chem-film and three coats of Koropon. Pitting corrosion has been noted on these set-back surfaces, particularly near drain tubes. Figure 2 shows an overview of corrosion found on the WLE behind three adjacent RCC panels on OV-102. The pattern of the pitting suggests a galvanic effect due to the drain tube, as shown in figure 3. This area does not receive a conditioned GN_2 purge. Typical damage detection during a flow is approximately 30 pits per wing averaging 0.010 inches deep.

See original document for figures.

Figure 2. Overall view of WLE spar corrosion found on OV-102 behind left-hand RCC panels 8, 9, and 10. Each brown-colored arrow points to a pitting location.

See original document for figures

Figure 3. Close-up view of galvanic corrosion site near a drain tube behind RCC panel 12 of OV-103's right-hand wing. Paint and corrosion product have been removed.

b. Rudder Speed Brake. The RSB is made of conventional aluminum ribs and spars with aluminum honeycomb skin panels. The honeycomb facesheet surface has been chem-filmed and has had two coats of Koropon and a polyurethane topcoat applied. Pitting corrosion, primarily adjacent to stainless steel fasteners, as shown in figure 4, has been detected on all orbiters. Dissimilar metal corrosion has also been detected near or beneath the Inconel thermal barriers, as shown in figure 5. This problem was corrected with a design change which added a barrier layer of RTV. Typical damage detected during each processing flow is from 30 to 60 pits approximately 0.001 to 0.017 inches deep. Tracking of PRs detected a trend of increased corrosion after 6 years of service. A detailed visual inspection of the RSB honeycombed facesheet is performed during every orbiter processing flow. Like the WLE spar, this area does not receive a conditioned air purge. There is a Rockwell-Downey proposal to strip the surface down to bare aluminum every 6 years and repaint, including coats of Koropon and polyurethane. This stripping and repainting has been approved for implementation on OV-102 during OMDP-1. Recently, washing of the RSB panels has been instituted. The goal of this washing is to remove any corrosive contaminants which may be introduced from the salt spray environment at the pad.

c. Dome Heat Shields. Components on the dome heat shields have a history of corrosion. Most problem reports document surface corrosion, which was cleaned with isopropyl alcohol. Recently, more serious stress corrosion cracking (SCC) has been detected. The components with corrosion are made of 17-4 and 17-7 PH, TH1050 (CRES), which has a low resistance to SCC. A material change request (MCR) and an engineering change order (ECO) have been written to change the dome ring covers of the dome heat shield to Inconel 718, which has a higher resistance to SCC. Similar changes may be warranted for other dome heat shield components. All dome heat shields are currently removed every flight for space shuttle main engine SSME removal and replacement. Inspections are performed on a sampling basis, with the entire dome heat shield being inspected within four flights.

d. External Tank (ET) Doors. The ET doors are made of beryllium and are adjacent to Inconel 718 edge fingers. Latch supports are attached to the doors. Pitting corrosion, shown in figures 6 and 7, has been detected at the beryllium/Inconel interface on at least two of the four orbiters. The pitting is too shallow to constitute an issue at this time. A temporary repair has been established in which the pits are cleaned of any loose active corrosion product, and those over 0.010 inches deep are potted with epoxy adhesive and covered with Koropon. Typical damage detected during each processing flow is 25 to 35 pits up to 0.010 inches deep per door. A permanent repair procedure is being developed considering the unique metallurgical and safety problems related to beryllium.

e. Auxiliary Power Unit (APU) Cavities (56-01 and 56-02). The left-hand and right-hand APU tank servicing port has been experiencing some corrosion pitting. The corrosion has been found on the side wall frame at the service panel interface area. Corrosion has been found on OV-102 (maximum pit depth 0.049 inches) and OV-103 (maximum pit depth 0.037 inches). During the inspection of OV-102, it was revealed that the RTV coating was missing at the interface between the side wall frame (aluminum) and the service panel (titanium). This RTV coating was applied during rework. A decision was made by the CCRB to inspect this interface on each orbiter and clean and coat faying surfaces with RTV when corrosion is suspected. The 56-01 and 56-02 cavities are inspected during each processing flow.

See original document for figures

Figure 4. Typical view of corrosion found on the RSB adjacent to stainless steel fasteners.

See original document for figures

Figure 5. Corrosion found on OV-103's RSB structure adjacent to the edge of an Inconel thermal barrier (removed).

See original document for figures

Figure 6. Overall view of pitting corrosion found at the beryllium/Inconel interfaces of the left-hand (LH2) ET door from OV-102.

See original document for figures

Figure 7. Close-up view of pitting corrosion of beryllium structure adjacent to an Inconel finger on the right-hand (LO2) ET door from OV-102.

4.2 Selected Unique Corrosion Issues

The following corrosion issues that have been addressed by the CCRB are not considered fleet-wide problems:

a. OV-102 Left-Hand (LH) Inboard Elevon. The OV-102 LH inboard elevon trailing edge, which is a honeycomb sandwich, was discovered to have a one-square-inch area of facesheet and core corroded away. It was determined to have been caused by improper sealing and placement of the elevon drain hole. The damage was repaired and the drain hole was relocated. The other vehicles are being inspected during OMDP for proper drain hole placement.

b. OV-102 Right-Hand (RH) Outboard Elevon. Scratches with corrosion were found in approximately 85 locations on OV-102's RH outboard elevon. The maximum pit depth was 0.004 inches. Possible causes were identified as (1) undetected corrosion in the skin at time of manufacture with subsequent application of Koropon and/or (2) scratches caused by improper tile removal.

c. Wing Carry-Through Spar. V30 inspections have discovered corrosion of the wing carry-through spar structures on OV-102 and OV-103. On OV-102 corrosion was found near the lower skin to 1307 bulkhead, three areas on the LH side (with a maximum pit depth of 0.0245 inches), and one area on the RH side (with pit depth of 0.0047 inches). On OV-103 corrosion was found around Hi-loks on the RH and LH 1307 bulkhead fittings and on various areas on the RH and LH lower bulkhead. The deepest pit found on OV-103 was 0.016 inches. All areas were cleaned and the corrosion was blended out, followed by applications of chem-film and Koropon to return the areas to print.

d. Body Flap Cove. Corrosion was recently discovered in the body flap cove of OV-103, shown in figure 8. Two areas of corrosion were noted: (1) rivets in the cove area and (2) at the actuator fitting to airframe faying surfaces. Corrosion of the rivets has been attributed to a galvanic couple between the aluminum rivets and titanium actuator fittings. Structural analysis indicated that the need for the rivets was minimal. The rivets are not replaced until 30% of the exposed head is missing. The actuator fitting corrosion was pitting. These areas were all cleaned and re-Koroponed. Mold impressions revealed defect dimensions 0.623 inches long, 0.195 inches wide and 0.023 inches deep; the fitting in this area is 0.080 inches thick. These items are currently under review by the CCRB.

5.0 Subsystem Corrosion History

In the orbiter history a number of corrosion issues have been documented within the various subsystems.

a. Ammonia Boiler. The ammonia boiler is a heat exchanger in the primary cooling loop for the payload bay and the cabin instrumentation. The ammonia boiler removes heat from the Freon cooling fluid as the Freon passes through a tube bundle by boiling the liquid ammonia which is vented off the orbiter. Accidental contamination of these tube surfaces before brazing resulted in the sensitization of these thin walled tubes (0.008 inches) made of type 304L stainless steel. The sensitized tubes were attacked and penetrated by the ammonia.

See original document for figures

Figure 8. Corrosion found on the body flap cove structure from OV-103.

The corrective action was to change the tubing to 347 stainless steel, which is not susceptible to the chromium carbide segregation, and to upgrade cleaning procedures to prevent contamination.

b. <u>APU Gas Generator Valve Seats.</u> The APU gas generator valve module (GGVM) utilizes four tungsten carbide valve seats to regulate hydrazine flow to the catalyst bed. The 5 mm diameter valve seats have sealing lands that are only 0.115 to 0.150 mm wide.

The seats are manufactured from sintered KZ-96 tungsten carbide containing 5% cobalt as a binder. In mid-1985, valve leakage problems during acceptance tests were traced to a breakdown of the valve seat lands. After an APU was shut down during a flight, contamination traces were found on one of the valve seats. The manufacturer instituted a revised cleaning process involving a hot water rinse for both production and refurbishment. Shortly after that, the valve seat lands began experiencing an extremely high rejection rate during acceptance test procedure (ATP). A subsequent failure analysis indicated that the hot water was leaching the cobalt binder from the valve seat lands.

A few years later, the valve seats began experiencing frequent leaking problems. Failure analysis indicated that ammonium hydroxide formed by the decomposition products of hydrazine and water condensation from the atmosphere backflowing down the vent duct were apparently initiating a cobalt leaching problem similar to that experienced previously. Tests proved that such exposure induced leaching and subsequent impacting of the lands by the valve poppets resulted in breakdown of the seats and the noted leakage problems.

c. APU Injector Tubes. The injector tube of the orbiter APU carries hydrazine fuel to the catalyst bed, where it is heated and decomposes. The hot decomposed gases drive a turbine wheel to generate secondary power for spacecraft systems. Shortly after touchdown from the ninth launch of the orbiter, two of the three APUs experienced fires. Extensive investigation determined that the fires resulted when hydrazine leaked through cracks in the Hastelloy nickel-based alloy B injector tube walls while on orbit and froze on exterior surfaces, and then melted and ignited during reentry.

The fractures on each tube were intergranular, starting on the inside diameter, and occurred in the same location. The cracks were determined to be caused by stress corrosion. It was determined that ammonia or ammonium hydroxide were the only potential fluids that could cause SCC on the Hastelloy B. The ammonia vapors resulted from the decomposition of the hydrazine in the catalyst bed. Moisture, resulting in the formation of ammonium hydroxide, was available from the atmosphere migrating back through the exhaust duct. Misalignment of the tubes during installation resulted in the stresses. A sensitized microstructure was also found, and was determined to be a result of carbon deposition during the electrical discharge machining (EDM) of the injector tubes.

The solution was to eliminate the preload stresses on the injector tubes by instrumenting the installation and to eliminate the sensitized carbide network by reaming the tube inside diameter and by revising the braze process to ensure even distribution of any carbides. Later tubes were also coated with a thin chromized layer.

d. Water Spray Boiler (WSB). The WSB cools the hydraulic and lubrication fluids by spraying water onto a hot tube bundle with the fluids flowing through it. The tube bundle is 321 stainless steel, and the outer shell is 6061 aluminum. The boiler is experiencing pitting corrosion of the aluminum shell (fig. 9). The corrosion protection in place is a Teflon-infused anodized coating. The pits typically occur at sharp corners or near the stainless steel spray tubes on the interior.

It was determined that the galvanic potential between the tubes and the shell was driving pit formation at local weak spots in the coating. Contributing to this was the conversion of the water to steam in the boiler, which concentrates all the impurities in the water.

A design change was approved to replace the shell material with Inconel 718 which is galvanically similar to the stainless tubes and not subject to crevice corrosion.

e. Flash Evaporator. The flash evaporator is used to reject orbiter heat loads from the Freon-21 coolant loops during ascent and entry, and to supplement the radiators in orbit. There are two flash evaporators in one envelope. The evaporators are cylindrical and have a finned inner core. The hot Freon from the coolant loops flows around the core. Water is sprayed onto the core, where it flashes to steam and cools the Freon. The evaporator draws its water from potable water storage tank B. There are four potable water storage tanks on each orbiter that are manifolded together. The water is supplied by the fuel cell power plant which generates water as a byproduct. The astronauts draw their drinking water from tank A, which has what is termed a "microbial check valve" upstream that dispenses iodine into the water as a biocide. Prior to launch, all the storage tanks are filled with water containing 25 ppm iodine.

Three instances of corrosion have occurred on flash evaporators, all associated with iodine. Pitting corrosion occurs in the anodized aluminum core from the water side to the Freon side, with iodine present in the corrosion products. A resolution to this item is currently in work.

See original document for figures

Figure 9. Water spray boiler corrosion, inner diameter of outer shell.

6. <u>Forward Reaction Control System (FRCS) Tubing.</u> The tubing assembly for the FRCS supplies the connection from the MMH and N2O4 storage tanks to the thrusters. The FRCS tubing assembly in OV-105 was undergoing final assembly and test when several welded tube joints were found to be leaking. The welded tube joint is a sleeve weld joint, consisting of two tubes butted against each other with a sleeve over the joint. A weld is then made which joins both tube ends and the sleeve with the sleeve acting as filler. The tubes were of 304L stainless steel and the sleeves could be either 304L, 321, or 347 stainless steel. Upon metallographic examination, a dissolution type corrosion was found to be taking place along the heat-affected zone, somewhat akin to "knife-line" attack. The nature of the sleeve weld produces crevices at the ends of the sleeve between the tubes and the sleeve. An electrochemical etch procedure was being used to mark the tube with an x-ray identification number adjacent to each joint after it was radiographically inspected. The acid etchant was wicking into the crevice as it was being rinsed off the tube and preferentially etching out the delta ferrite phase in the weld metal.

6.0 Unanticipated Environments

6.1 Extended Pad Stays

Normal STS processing includes a scheduled period at the pad for payload installation, final servicing, and checkout prior to launch. The average pad stay is approximately 31 days. During twelve pad stays, problems that arose with the flight hardware extended the time normally spent at the pad. The longest time spent at the pad was 166 days prior to OV-102's tenth flight. Table 2 summarizes the pads stays for each vehicle.

These extended stays at the pad are of concern to the CCRB. The pad is located a few hundred yards from the ocean. The coast exposure is very severe because of the heat, high humidity, salt air, and the daily condensation of dew deposited onto the orbiter structure. The orbiter TPS bonding system provides adequate corrosion protection under most circumstances. Exterior assemblies on the orbiter that are not covered by the thermal protection system (RSB, WLE spar, and ET doors) are primed with Koropon and in some cases also painted. Condensation can occur on these surfaces, which may initiate corrosion activity when the primer/paint barrier is violated. These areas have shown repetitive corrosion problems, as stated earlier in this report. The CCRB is actively working to address these corrosion issues. A possible solution is expanding the present purge system to cover additional areas.

6.2 Pad Firex System

The pad is equipped with a Firex system that is activated when fire hazards, including gas leaks, are detected near the orbiter. The system is designed to spray the specific external area of the orbiter where a fire hazard has been detected.

The water used in the Firex system is filtered, untreated water. Since a main engine abort normally requires a minimum of a week to resolve, the designed drainage system along with normal evaporation should dry out these areas. Although the water in the tank reservoir is filtered, there may be stagnant water in the lines that contain various ionic contaminants. This water could act as an electrolyte if introduced into the orbiter.

There are three systems which make up the Firex system at the pad. It is suspected that past uses of these systems may have contributed to previous structural corrosion problems. These systems and the times they have been used:

> Orbiter SSME Water Deluge System—This system is automatically turned on by the ground launch sequencer during an abort. This deluge covers the main engine nozzles/heat shield area and the 17" disconnect area. During operation of this system, the Rudder Speed Brake is subject to a considerable amount of deluge. This system operates for 2-10 minutes, depending on the abort conditions. The system is manually shut down.
>
> Times used: OV-099, 41C; OV-103, 51A; OV-099, 51F; OV-103, STS-26R FRF; OV-105, STS-49 FRF; OV-102, STS-55; OV-103, STS-51; OV-105, STS-68.

Table 2. Pad Stays

			ROLL		TOTAL PAD
	STS	FLT	TO PAD	LAUNCH	STAY (DAYS)
OV-102	STS-1	1*	Jan 1, 81	Apr 12, 81	102
	STS-2	2*	Sept 4, 81	Nov 12, 81	70
	STS-3	3	Feb 20, 82	Mar 22, 82	31
	STS-4	4	May 31, 82	Jun 27, 82	28
	STS-5	5	Oct 5, 82	Nov 11, 82	38
	STS-9	6	Nov 13, 83	Nov 28, 83	15
	61C	7	Dec 26, 85	Jan 12, 86	18
	28R	8	Jul 14, 89	Aug 08, 89	25
	32R	9	Nov 28, 89	Jan 9, 90	42
	35	10*	Apr 22, 90	Jun 12, 90	51
			Aug 9, 90	Dec 2, 90	115 166
	40	11	May 2, 91	Jun 5, 91	34
	50	12	Jun 3, 92	Jun 25, 92	22
	52	13	Sep 25, 92	Oct 22, 92	26
	55	14*	Feb 7, 93	Apr 26, 93	78
	58	15	Sep 17, 93	Oct 18, 93	31
	62	16	Feb 10, 94	Mar 4, 94	21
					Total: 726
OV-103	41-D	1	May 19, 84	Aug 30, 84	38
	51-A	2	Oct 23, 84	Nov 8, 84	16
	51-C	3	Jan 5, 85	Jan 24, 85	19
	51-D	4	Mar 28, 85	Apr 12, 85	16
	51G	5	Jun 4, 85	Jun 17, 85	14
	51-I	6	Aug 6, 85	Aug 27, 85	21
	26R	7*	Jul 4, 88	Sep 29, 88	87 FRF 29R
	8	Feb 3, 89		Mar 13, 89	38
	33R	9	Oct 27, 89	Nov 22, 89	26
	31R	10	Mar 16, 90	Apr 24,89	39
	41	11	Sep 4, 90	Oct 6, 90	32
	39	12*	Feb 15, 91	Mar 14, 91	27
			Apr 1, 91	Apr 28, 91	27 54
	48	13	Aug 12, 91	Sep 12, 91	31
	42	14	Dec 18, 91	Jan 22, 92	35
	53	15	Nov 8, 92	Dec 2, 92	24
	56	16	Mar 15, 93	Apr 8, 93	24
	51	17*	Jun 26, 93	Sep 12, 93	78
	60	18	Jan 5, 94	Feb 3, 94	30
					Total: 592
OV-104	51-J	1	Aug 30, 85		Oct 3, 85 35
	61-B	2	Nov 12, 85	Nov 26, 85	15
	27R	3	Nov 2, 88	Dec 2, 88	30
	30R	4	Mar 22, 89	May 4, 89	43
	34	5*	Aug 29, 89	Oct 18, 89	50
	36	6	Jan 25, 90	Feb 28, 90	34
	38	7*	Jun 17, 90	Aug 8, 90	52
			Oct 12, 90	Nov 15, 90	34 86
	37	8	Mar 15, 91	Apr 5, 91	21
	43	9	Jun 25, 91	Aug 2, 91	38
	44	10	Oct 24, 91	Nov 24, 91	31
	45	11	Feb 19, 92	Mar 24, 92	33
	46	12*	Jun 11, 92	Jul 31, 92	50
					Total: 466
OV-105	49	1*	Mar 13, 92	May 7, 92	55 FRF
	47	2	Aug 25, 92	Sep 12, 92	18
	54	3	Dec 3, 92	Jan 21, 9	41
	57	4*	Apr 28, 93	Jun 21, 93	54
	61	5	Oct 28, 93	Dec 2, 93	35
					Total:
203					

"*" = Considered "Extended Pad Stays" (>50 Days)

Excluding "*" Flights, Avg Pad Stay: 31 Days

LH2/LO2 T-0 Water Deluge System—This system is manually operated from the launch control center (LCC). The deluge covers the LH_2 and LO_2 T-0 umbilical areas.

Time used: OV-099, 51F

Orbiter Skin Spray System—This system is manually operated from the LCC. The deluge covers the 50-01 and 50-02 aft access doors and surrounding areas.

Time used: Never used.

6.3 OPF Firex System

During the OPF processing of OV-102, STS-32R, the fire protection system was inadvertently activated. The system operated for several minutes, releasing an undetermined amount of water. The orbiter was configured with the payload bay doors open, the flipper doors open, and the body flap off. A large amount of standing water was removed from the midbody floor along the centerline of bay 13, back to the Xo 1307 bulkhead. The horizontal processing orientation of the orbiter in the OPF creates a low point at this area, and there is no drainage system in place. Water was also removed from the elevon cove areas. Since the incident, minor corrosion has been noted at the lower bulkhead structure. The midbody wing carry through structure is being addressed by the CCRB.

6.4 Water Intrusion

Occasionally rain water intrusion occurs during pad stays, orbiter ferry, or SCA off-loading at the MDD. Water can enter through vent doors, access panels, mating sections and the payload bay doors. Although there is a horizontal drainage system (see section 2.4), standing water is still found at some low lying areas. This water is immediately removed upon access to the areas. The CCRB is concerned that inaccessible water may have wicked into structural joints.

6.5 Fuel Spillage

The orbiter carries hypergolic fuel (MMH) and oxidizer (N_2O_4) in tanks within the FRCS and the OMS pods to power orbiter maneuvering engines and thrusters. Spilling of these hypergolic fluids during the transfer or leaking of the thrusters due to faulty hardware exposes the OMS pod and FRCS structure to chemicals highly corrosive to the metal airframe components. Other corrosive materials used in and around the orbiters are N_2H_4, for the APU, and NH_3 in the ammonia spray boiler. the most notable instance of corrosion caused by fuel spillage occurred at the APU servicing panels. This incident is covered in detail in a previous section.

7.0 Access

Long-term planning for the maintenance and inspection of the orbiters was not given full consideration until after the orbiters were already constructed. As a result, many areas of the structure are difficult to access for corrosion inspection. Subsystem components, such as wire bundles, tubing, ducting, tanks, thrusters and line replacement units (LRUs) obstruct structure, some of which is significant. Borescopes are used extensively to inspect in locations where access is limited.

A concern for inspecting the orbiter external surface for corrosion is that most of it is covered with thermal protection system (TPS), which includes tiles, flexible insulation blankets, and felt reusable surface insulation. In many cases, the interior surface is accessible for inspections which allow for detection of through corrosion conditions. Tile removal necessary for TPS servicing, as well as a sampling plan to ensure TPS integrity, provides random access to some of the structure every flow. However, the TPS limits the amount of structure available for inspection.

The interior structure of the orbiter is often lined with TCS blankets, which also obstruct access to the structure for the performance of corrosion inspections. Although these blankets can sometimes be removed or lifted to provide access, in some areas blanket removal would require destroying the blankets, and reinstallation would be impossible without structural disassembly. An example is the cavity between the forward fuselage and the crew module pressurized cabin. This area varies from approximately three feet to only a few inches and encompasses the entire area surrounding the crew module (excluding windows and airlock hatches). Another passive TCS obstruction to inspections is RTV heat-sink material, which is applied to the payload bay floor and the forward reaction control system cavity. Sampling inspection techniques in which strips of RTV are removed to inspect the skin underneath are employed in these cases.

There are also cavity interiors, such as those within the rudder speed brake, that require inspection for corrosion but are only accessible with a borescope. Although there are some indications of minor corrosion forming within these cavities, access for further investigation and corrosion control is limited without cutting into or disassembling the structure.

8.0 Training/Inspection Criteria

All recurring inspections for corrosion, as prescribed in the V30 OMRSD file, are performed by a joint team of one NASA and one contractor inspector. NASA and contractor quality inspectors are spacecraft professionals experienced in detecting corrosion and other anomalies.

Candidates for training to be an inspector for the shuttle program must possess proper qualifications, such as an FAA airframe and power plant (A & P) license, prior experience as an orbiter technician, or prior related employment in the aerospace industry.

Inspectors are required to complete an on-the-job training (OJT) program before being allowed to perform an inspection unaccompanied. The OJT program was established to ensure that personnel are trained and qualified in a comprehensive, detailed, and controlled manner. OJT is conducted by quality supervisors or designated senior inspectors. The trainer-to-trainee ratio is limited to optimize training. As the trainer and the trainee agree that the trainee is comfortable with the tasks, safety measures, and reference material necessary to perform a given job assignment, that task is signed off in the OJT package as complete, and the inspector is permitted to perform that task unassisted in the future. OJT packages constitute records to ensure proper qualification for a given job assignment.

One persistent issue identified early in the CCRB review process is that a general inconsistency exists between field inspection, assessment, and reportingprocedures and the engineering perception of corrosion problems. The CCRB has served as an independent body for the resolution of such issues and will continue to provide assistance in this area. However, the solution to this problem has been identified as primarily one of review, understanding, and modification of existing inspection procedures to reflect the expectations of the combined engineering community, and subsequently communicating these expectations to operations personnel. Consequently, the CCRB has worked closely with the appropriate engineering disciplines in generating revised or entirely new corrosion inspection and rework procedures on a case-by-case basis, as issues are addressed. The board has initiated a program of technician training at KSC in order to improve the confidence and reliability of assessments.

As an aid to training in detecting corrosion, LSOC Quality Engineering developed a Corrosion Training Manual in 1993, using current aeronautical and military aircraft maintenance sources. All quality control supervisors received training in use of the manual. The manuals were distributed to all quality control inspectors through their supervisors. Corrosion inspection training has received a positive response from the participants. The CCRB will continue to monitor the training program on a regular basis.

9.0 Analysis/Discussion

During calendar year 1993, the CCRB reviewed a total of 26 formally documented orbiter corrosion issues representing new corrosion-related anomalies as well as more persistent, long-term problems. For purposes of the discussion in this section, these issues are divided into arbitrary, but functional, classifications: problems associated with mechanical subsystems (13) and problems associated with primary or secondary structure (13), as summarized in table 3. In the course of this review, additional related issues were addressed so that the number of actual topics is substantially greater than the number formally entered into records.

Of the 13 structural corrosion issues reviewed, 12 (93-1 through -5, -7, -10, -13, -17 and -21 through -23) were attributed to the effects of environmental/atmospheric exposure, and 1 (93-6) to contamination during hardware processing. Structural corrosion due to atmospheric exposure was discussed on a regular basis throughout the course of CCRB meetings during 1993. An explanation for this concentration of effort was pursued through an analysis of the CCRB corrosion database [1].

In terms of the frequency of corrosion occurrences at various vehicle locations, the corrosion database shows that of the 981 entries in the corrosion database, 926 records have respective associated zonal locations [2] listed, as summarized in table 4.

Table 4 suggests that a large number of documented corrosion problems are associated with aft sections of orbiter vehicles (major zones 3xx, 4xx, and zones 540 and 550 (right and left OMS/RCS), 651-653 and 751-753 (right and left inboard elevon, outboard elevon, and wing extension box, respectively), 860 and 870 (right and left ET umbilical doors, respectively). The conclusions drawn from table 4 are supported by further analysis of the corrosion database, showing that more than 50% of the entries are associated with aft sections. During the study of the database, it was noted that, with the exception of zones 540 and 550, nearly all of the aft-identified entries are structural corrosion issues.

These findings substantiate the CCRB concern for corrosion of orbiter structure. The above analysis excludes structural corrosion issues associated with the wing leading edge spar located in the vehicle mid-section (133 issues documented, representing 13.6% of the total number of records). In addition, the data support the expectation that corrosion should be most severe in what becomes the lower sections of an orbiter vehicle when it is positioned in the vertical launch orientation, especially during the critical periods of outdoor exposure that include salt mist and rain (refer to section 2). Aft sections that are left relatively unprotected by the TPS are particularly susceptible to atmospheric exposure. As an example, the RSB and body flap cove locations account for 16% of all corrosion anomalies.

Table 3. Activity Summary and Classification of CCRB Issues CY 1993

ID Number	Issue	Subsystem	Structure
93-1	RSB Internal		x
93-2	RSB External		x
93-3	Wing Leading Edge Spar		x
93-4	Body Flap Rivets		x
93-5	Corrosion Under Tile		x
93-6	APU Cavity		x
93-7	ET Door		x
93-8	OMS Engine	x	
93-9	Water Spray Boiler	x	
93-10	Dome Heat Shield		x
93-11	Ammonia Boiler	x	
93-12	Body Flap Actuator	x	
93-13	Elevon Cove Seal		x
93-14	MPS Manifold Relief Valve	x	
93-15	3-Way Solenoid Valve	x	
93-16	Freon Cooling Loop	x	
93-17	Water Intrusion/Entrapment		x
93-18	RSB Actuators	x	
93-19	Training		
93-20	Corrosion Database		
93-21	Wing Carry Through Spar		x
93-22	RSB Through Pitting		x
93-23	O2N2 Relief Port		x
93-24	OMS/RCS 17-4 PH Pitting	x	
93-25	MPS Iron Oxide	x	
93-26	FCPV Leakage	x	
93-27	ON2 Check Valve	x	
93-28	OV-104 Potable Water System	x	

Table 4. Corrosion Incidence by Orbiter Zone Location (926 of 981 entries)			
Zone	Description	Number of Occurrences	Percent of Total
1xx	Forward Fuselage	62	6.7
2xx	Mid Fuselage	41	4.4
3xx	Aft Fuselage and Body Flap	315	34.0
4xx	Vertical Stabilization Control Systems	100	10.8
5xx	OMS, SSME, FRCS Modules	139	15.0
6xx	Right Wing	115	12.4
7xx	Left Wing	99	10.7
8xx	Nose Cap, Hatches, and Doors	24	2.6
9xx	Landing Gear and Landing Gear Doors	31	3.4

In addition, corrosion in aft locations is apparently accelerated by occasional exposures to unusually severe corrosive environments, e.g., the water deluge that follows a launch pad abort. Although clear fresh water is intended for performing the deluge, verbal testimonials indicate that some level of contamination is introduced by this procedure. The most recent example of apparent water deluge effects is the relatively severe corrosion of fasteners and structural panels in the OV-103 body flap cove detected prior to STS-60 (Problem Report PV6-255792). Corrosion was reported on most rivets, at the fitting-to-airframe faying surface, and on outboard secondary structure; the most severe localized attack on the structure extended to a measured depth representing 28% of the total section thickness. At the time of this report, the water deluge issue is under study for specific details concerning the history of recent processing flows, in order to establish the connection to water deluge effects.

Although the aft areas are coated with corrosion-resistant Koropon primer (and in the case of the RSB, with an additional polyurethane topcoat), the organic coatings slowly deteriorate with time and eventually become ineffective in their ability to resist corrosion. Degradation of the standard Koropon/polyurethane coating system over a 4 to 6 year period has been cited in the engineering literature [3]. This time interval has been substantiated for the RSB, as evidenced by the increase in the number of PRs as the vehicle ages.

9.1 Materials

Aluminum 2xxx-series alloys account for the overwhelming majority of structural corrosion problems. The alloys are present in the form of rivets, monolithic panels, and thin (less than 0.020 in. thick) facesheet honeycomb. A notable exception to the corrosion problems associated with these materials is the high incidence of issues associated with the SSME dome heat shields, which are fabricated from 17-7 PH stainless steel (143 occurrences representing 15% of all corrosion database entries).

9.2 Mechanisms

Corrosion of structural elements is attributed to atmospheric corrosion mechanisms which can operate during any portion of the ground cycle (refer to section 2.1a), but are most active when the orbiter resides on the launch pad. This period is typically on the order of 30 days, but schedule delays have caused extensions of this period up to 115 days. Under normal ambient atmospheric conditions and in the presence of moisture, corrosion of exposed surfaces occurs in the presence of oxygen, which provides the coupling cathodic reaction for active, anodic corrosion. In addition, when oxygen is present, faying surfaces are susceptible to crevice corrosion. The salt air environment encountered at the KSC launch facilities serves to further enhance the conditions for corrosion, especially pitting phenomena. As discussed in section 5.2, the degradation of primer integrity is an important factor in predisposing structure to high corrosion rates under these conditions.

For certain configurations of structure, galvanic corrosion conditions are superimposed on atmospheric effects and most likely represent the predominant, rate-determining corrosion mechanism. Under conditions of galvanic corrosion, the cathodic counter-reaction typically occurs at a second metal which is dissimilar to the corroding anode. Furthermore, there is a marked dependence upon the relative anode/cathode area ratio, as illustrated in figure 10 [4]. Small area ratios result in accelerated galvanic attack on the anode. Most orbiter structure problems with galvanic corrosion and small anode/cathode area ratios typically occur in situations where aluminum rivets are located adjacent to stainless steel or Inconel fittings, although corrosion of the wing leading edge spar is attributed to galvanic coupling of the aluminum structure to the Inconel thermal insulators.

9.3 Mitigation System

The long-term goal of the CCRB is to facilitate the evolution of the existing maintenance framework into a more comprehensive corrosion prevention and control program. Such a program should translate past operational experiences into an integrated network of practical inspection strategies, consistent rework procedures, timely engineering involvement, and the utilization of new corrosion prevention technologies.

Basic requirements for inspection and maintenance of orbiter structural corrosion-related problems are found in OMRS V30 and V31 documents, and operations efforts have been performed in full compliance with these requirements. Given the original design lifetime of 10 years, the current maintenance program would likely be adequate to maintain structural integrity of the vehicle.

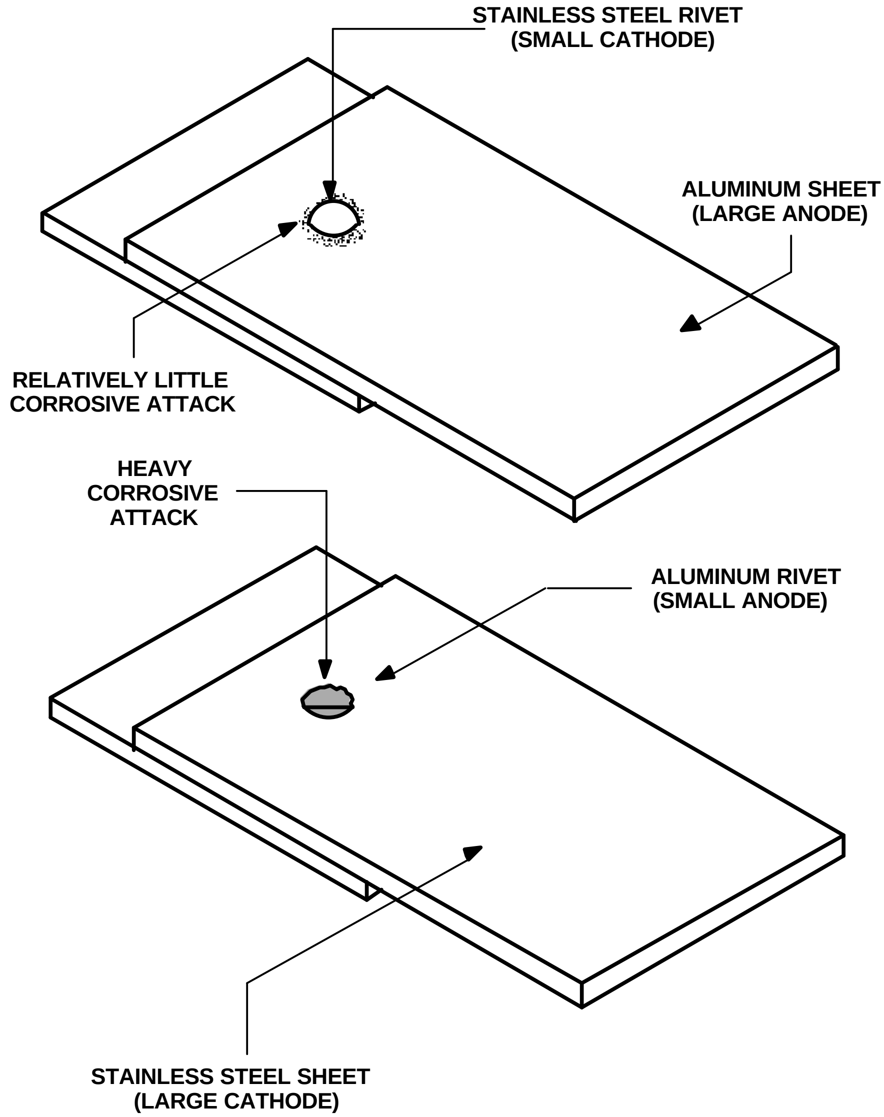

Figure 10. Effect of area relationship in dissimilar metal contacts (from [4]).

However, the anticipated extensions of orbiter life, the persistence of certain structural corrosion issues, and the lack of structural spares have necessitated an ongoing review of the maintenance process.

An outgrowth issue of the above discussion is that there is no single, comprehensive reference source of rework limits for orbiter structure. This information is commonplace in both military and civilian aerospace industries, and is necessary for rework procedures, such as cleaning and blendouts, to be implemented efficiently and safely. At present, the effects of rework on stress margins must be evaluated on an individual basis, which greatly extends the time span required to complete these procedures. Blendout limits serve a gatekeeping function by defining acceptable maximum depths of rework for any given single rework operation. In addition, they allow the accurate evaluation of corrosion severity for a given structure, as determined by the rate at which blendout limits are approached by a succession of rework operations. The CCRB has addressed this problem on an informal level with the engineering community, and is continuing its attempts to obtain a satisfactory resolution.

Corrosion protection strategies endorsed by the CCRB in 1993 focused on corrosion prevention and control methodologies which apply currently approved orbiter materials and processes. This approach was used in order to avoid large materials qualification efforts and, therefore, maximize the cost benefit of corrosion protection strategies.

RTV has been used in several rework applications involving galvanic corrosion of faying surfaces, and approved lubricants have been recommended for use as water-displacing agents in certain interim dispositions. In addition, regular washing of the RSB with an approved alkaline detergent has been implemented in order to reduce the incidence of corrosion on this structure; this procedure is structured after the military policy on aircraft washing [4]. Because of the relatively high incidence of RSB corrosion and coating degradation, as discussed earlier, there is a development effort in work to periodically strip and repaint the RSB.

At present, the use of approved orbiter materials is at or near the limit of their collective applicability to corrosion prevention. Although the corrective actions implemented to date represent improvements relative to previous efforts, concerns persist over continued corrosion of susceptible structure such as the RSB and body flap cove, the possibility of exceeding finite rework limits, and the additional issue of physical inaccessibility of certain structures. In such areas, additional corrosion protection requires the development and qualification of new corrosion protection technologies, such as corrosion preventive compounds and advanced coatings. The potential use of new corrosion technologies on orbiter structure will be addressed a future report.

10.0 Summary

Corrosion of the orbiter fleet to date, particularly orbiter structure, has been relatively benign. Although it may be reasoned that any corrosion is cause for concern, no corrosion problem has ever caused such a disastrous event as a launch delay, in-flight failure, or safety hazard. The most serious problems have generally been associated with nonstructural subsystems such as the hydrogen separator and the flash evaporator.

Corrosion protection systems on susceptible surfaces have performed remarkably well. Breakdowns generally have occurred where exposure has been greater than expected, typically due to extended pad stays. Surface coatings do wear out, however, and the CCRB has initiated the reapplication of Koropon primer and paint on some structure.

The potential for undetected corrosion has generated significant concern from time to time. Other than skin under TPS and sealed structure, honeycomb structure presents the most challenging corrosion inspection problem. Two instances of corrosion in aluminum honeycomb have occurred due to a lack of adequate drainage. Both of these instances were traced to errors during manufacturing and/or previous repair. The CCRB has undertaken the responsibility for actively searching for structure that cannot easily be inspected and is studying these areas for corrosion potential.

Although the number of corrosion reports may be expected to increase as the orbiter fleet ages, there is no reason to believe that the relative significance of corrosion issues, particularly structural corrosion issues, will change. However, a continuous “total vehicle” approach to corrosion should be maintained. The CCRB will retain the initiative for identifying future corrosion problems and will become more aggressive concerning corrosion prevention.

References

1. Orbiter Corrosion Control Review Board, Corrosion Database, February 25, 1994.

2. SPC Document #LSO-092-039-9060, Orbiter Zone and Access Locator, Volume I: Zone Identification Guide, Shuttle Processing Contractor Operations Analysis, 1992.

3. C.R. Hegedus, D.F. Pulley, S.J. Spadafora, A.T. Eng, and D.J. Hirst, “Organic Coatings - First Line of Defense,” Advanced Materials and Processes 139 (1989) 62.

4. NAVAIR T.O. 1-1-691, “Aircraft Weapons Systems Cleaning and Corrosion Control,” January 1, 1992.

5. ASM Metals Handbook, Lawrence J. Korb, 9th Edition, “Corrosion in the Aerospace Industry,” 1987.

6. Space Shuttle Operations and Maintenance Requirements and Specification Document V30 File III, “Orbiter OMRSD Air Frame Inspection,” January 3, 1992.

7. Space Shuttle Operations and Maintenance Requirements and Specification Document V30 File III, “Orbiter OMRSD Zonal Inspection,” January 2, 1992.

8. R.A. Starner, Pan Am Shuttle Team Leader, “Shuttle Orbiter Structural Inspection Requirements Report,” October 18, 1983.

9. R.A. Starner, Space Shuttle Maintenance Assessment Project, “Development and Application of the SMSG-1 Analysis to the Shuttle Orbiter,” September 22, 1987.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*

2. REPORT DATE
June 1995

3. REPORT TYPE AND DATES COVERED
NASA Technical Memorandum

4. TITLE AND SUBTITLE
Space Shuttle Orbiter Corrosion History, 1981-1993: A Review and Analysis of Issues Involving Structures and Subsystems

5. FUNDING NUMBERS

6. AUTHOR(S)
Orbiter Corrosion Control Review Board, editors

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Lyndon B. Johnson Space Center
Houston, Texas 77058

8. PERFORMING ORGANIZATION REPORT NUMBERS

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
TM-1995-104810

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Available from the NASA Center for AeroSpace Information (CASI)
7121 Standard
Hanover, MD 21076-1320

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The first space shuttle orbiter flight was launched on April 12, 1981. The original design life was 10 years or 100 missions. Since then, each orbiter except Endeavour (OV-105) has flown at least 12 missions; OV-102 (Columbia) has flown over 18 missions. Currently, plans are under consideration to continue flying the space shuttle until as late as the year 2020. Although the orbiter was designed for extended use, a review of corrosion mitigation methods is essential for an additional 25 years of operation. Although the orbiter flight and ground environment is often compared to that of commercial and military aircraft, there are significant differences. This is made evident by the relatively small number of orbiter corrosion problems experienced to date. However, trends indicate a gradual increase in corrosion reports in recent years, which is not unexpected as the orbiters age. The intent of this volume of the corrosion report is to review all measures taken to limit orbiter corrosion, from design considerations through operational maintenance. The corrosion that has occurred is analyzed to identify possible inconsistencies in rationale, unavoidable environmental conditions, and/or design shortfalls.

14. SUBJECT TERMS
orbiter, corrosion, age life, maintenance, design life, space shuttle

15. NUMBER OF PAGES
38

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

Standard Form 298 (Rev Feb 89) (MS Word Mar 97) NSN 7540-01-280-5500
Prescribed by ANSI Std. 239-18
298-102